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METHOD AND APPARATUS FOR LOGGING A WELL USING FIBER OPTICS

BACKGROUND

This invention generally relates to the logging and perforating of subterranean wells. More particularly, the invention relates to the logging of such wells using a fiber optic line.

Prior art logging systems have been deployed via electric wireline, known to those familiar with the art as braided cable, and via slickline. Wireline deployed logging systems are able to transmit the data collected by the logging tool real time through the electrically conductive copper wire, which is braided in with the braided steel wire. Although wireline deployed logging systems are able to transmit data real time via the electrical wires, such systems require a grease injector in order to ensure that pressure from the wellbore does not escape around the wireline as it is inserted into a pressurized well during deployment and use. Grease injectors, however, are problematic instruments to use, since they have a great tendency to leak under pressure and continual wear, and they present an environmental hazzard when such leaks occur.

On the other hand, current slickline deployed lines are manufactured from solid wire and are not able to transmit the logging tool data real time to surface. Instead, slickline deployed logging systems use memory tools connected to the lower end of the line. In slickline memory logging, the slickline and memory tool are lowered downhole on the end of the slickline and the memory tool is used to record the downhole logging tool data for subsequent download and collection at the surface once the tools are retrieved from the well. The advantages of slickline deployed systems are that they are much less costly and easier to deploy than wireline deployed

systems, they can be run in the hole and out of the hole faster than braided wire, and they are easier to seal against well pressures at the well head.

Thus, there exists a continuing need for an arrangement and/or technique that addresses one or more of the problems that are stated above. In particular, the prior art would benefit from a logging system that has the capability of transmitting the logging tool data real time to surface and that is as economical and as easy to deploy as slickline deployed systems.

SUMMARY

The invention is a system and method to log a wellbore, comprising a logging tool including a downhole power source to power the data transmission and logging tool, the logging tool adapted to be deployed in a wellbore environment, the logging tool taking at least one measurement of the wellbore environment, a fiber optic line in optical communication with the logging tool, and the logging tool transmitting the measurements on a real time basis through the fiber optic line to surface and converting the data at surface back into electrical data and processing the data at surface into a real time display of the data. In one embodiment, a continuous tube with one end at the earth's surface and the other end in the wellbore is attached to the logging tool and includes the fiber optic line disposed therein.

BRIEF DESCRIPTION OF THE DRAWING

Fig. 1 is a schematic of one embodiment of the logging system of this invention.

Fig. 2 is a schematic of another embodiment of the logging system of this invention.

DETAILED DESCRIPTION

Figure 1 shows the logging system 10 of the present invention disposed in a wellbore 5. Wellbore 5 may be cased. The logging system 10 includes at least one logging tool 12 and at least one fiber optic line 14. The logging system 10 includes at least one downhole power source 16, which can be a chemical battery, an optical to electrical power convertor, or a hydraulic turbine to electrical power convertor, to provide power to the different subcomponents 17 of the logging tool 12 including down hole data transmitters and receivers. A converter 18 is functionally attached to the logging tool 12 and the fiber optic line 14 and is located downhole in one environment. The converter 18 converts the electrical signals produced by the logging tool subcomponents 17 into optical signals that are then transmitted by an optical transmitter 20 through the fiber optic line 14 to the surface. Data collected by the logging tool subcomponents 17 is thus converted into electrical signals which are then converted into optical signals by the converter 18 and transmitted real time to the surface by the optical transmitter 20. Other data, such as tool status reports (i.e., active/not active, battery power, malfunctioning), may also be sent from the logging tool 12 through the fiber optic line 14 to the surface on a real time basis.

Logging tool subcomponents 17 may include but are not necessarily limited to a pressure sensor 22, a flow sensor 24 such as spinner 26, a gamma ray tool 28, a casing collar locator 30, an acoustical cement bond quality monitor, etc . Each subcomponent 17 collects its data and generates electrical signals indicative of such data. The electrical signals are then converted to optical signals as previously described. Other data gathering tools or subcomponents may include electrical or optical fluid analyzers, temperature sensors, chemical property sensors, and temperature sensors. In this application, the term "logging tool" is thus a tool that measures at least one parameter of the wellbore, wellbore environment, wellbore fluids, or formation (collectively referred to as "wellbore environment"). Likewise, the term "logging" is the taking

of measurements of at least one parameter of the wellbore, wellbore environment, wellbore fluids, or formation (collectively referred to as "wellbore environment"). Logging can occur while the tools are held stationary at a given depth or while the tools are moved up and down in the well bore simultaneously gathering data and transimitting said data to the surface through at least one optic fibre. It is understood that the term "logging tool" may include a plurality of subcomponents, each of which may measure a different parameter. In addition, a plurality of logging tools 12, each with at least one or a plurality of subcomponents 17, may also be used with this invention.

In one embodiment, the fiber optic line 14 is disposed within a conduit 32, which protects the fiber optic line 14 from the harsh wellbore fluids and environment. Conduit 32 also protects fiber optic line 14 from strain that may otherwise be induced during the deployment, logging, and recovery operations of the tools and optic fibre tube. Logging tool 12, as well as spinner 26, converter 18, and optical transmitter 20, are attached to the conduit 32, therefore the fiber optic line 14 located within the conduit 32 does not feel the weight of the logging tool 12. Conduit 32 is preferably a small diameter tube, such as 3/16" inches, that has a wall thickness large enough to support the logging tool 12 in addition to the weight of the tube and optic fibres disposed therein. In one embodiment, conduit 32 may be deployed on a reel such that the tube, fibres, and tools can be recovered a plurality of times from wells, the tools subsequently disconnected at surface and the reel with the tube and optic fibres can thus be transported to subsequent wells where tools will be reconnected to the tube and then redeployed in a different well. In one embodiment, Conduit 32 is a continuous tube that extends from the surface to the downhole logging tool(s) 12.

Wellhead 34 is located at the top of wellbore 5. Conduit 32 with fiber optic line 14 therein is passed through a stuffing box 36 or a packing assembly located on wellhead 34. Stuffing box 36 provides a seal against conduit 32 so as to safely allow the deployment of logging system 12 even if wellbore 5 is pressurized. In one embodiment, at least one additional seal 70, such as an elastomeric seal, can be located below the stuffing box 36 to provide an additional sealing engagement against the conduit 32 in order to prevent leaks from the pressurized wellbore escaping around the outer diameter of the conduit 32.

Conduit 32 may be deployed from a reel 38 that may be located on a vehicle 40. Several pulleys 42 may be used to guide the conduit 32 from the reel 38 into the wellbore 5 through the stuffing box 36 and wellhead 34. Based on the size of the conduit 32, deployment of the invention does not require a coiled tubing unit nor a large winch truck. Reel 38, in one embodiment, has a diameter of approximately 22 inches. Being able to use a smaller reel and vehicle than prior art coiled tubing logging with electrical and braided wire deployed logging systems dramatically reduces the cost of the operation.

Fiber optic line 14 is connected to a receiver 44 that may be located in the vehicle 40. Receiver 44 receives the optical signals sent from the logging tool 12 through the fiber optic line 14. Receiver 44, which would typically include a microprocessor and an opto-electronic unit, converts the optical signals back to electrical signals and then delivers the data (the electrical signals) to a processor, which processes the data and enables the presentation of the data to a user at surface. Delivery to the user can be in the form of graphical display on a computer screen or a print out or the raw data transmitted from the logging tool 12. In another embodiment, receiver 44 is a computer unit, such as lap top computer, that plugs into the fiber optic line 14. In another embodiment, the data is transmitted at surface to an internet and presented to users via a portal

on the internet. In each embodiment, the surface receiver 44 processes the optical signals or data from the down hole logging tools and optic fibre to provide the chosen data output to the operator. The processing can include data filtering and analysis to facilitate viewing of the data.

An optical slip ring 39 is functionally attached to the reel 38 and enables the connection and dynamic optical communication between the fiber optic line 14 and the receiver 44 while the reel is turning running the tube into the well or pulling the tube out of the well. The optical slip ring 39 interfaces between the fiber optic line 14 that is turning with the reel and the stationary optic fibre at the surface. The slip ring 39 thus facilitates the transmission of the real time optical data between the dynamically moving optic fibre inside the moving reel 38 and the stationary receiver 44 at surface. In short, the slip ring 39 allows for the communication of optical data between a stationary optical fiber and a rotating optical fiber.

In one embodiment, a plurality of fiber optic lines 14 are disposed in conduit 32. The use of more than one fiber optic line 14 provides redundancy to the real time transmission of the data from the logging tool 12 to the surface as well as increased optical power transmission to down hole tools and other devices like power sources. The use of more than one fiber optic line 14 also allows for both single and multimode optical fiber to be run.

In one embodiment, conduit 32 is deployed with fiber optic line 14 already disposed therein. However, in another embodiment, conduit 32 is first deployed by itself, and fiber optic line 14 is thereafter installed in the conduit 32. In this technique, which is described in United States Reissue Patent 37,283, fiber optic line 14 is pumped down conduit 32. Essentially, the fiber optic line 14 is dragged along the conduit 32 by the injection of a fluid at the surface, such as injection of fluid (gas or liquid) by pump 46. The fluid and induced injection pressure work to

drag the fiber optic line 14 along the conduit 32. This installation technique can be specially useful when a fiber optic line 14 requires replacement during a logging operation.

In the embodiment shown in Figure 1, optical transmitter 20 is located downhole with the logging tool 12. In another embodiment shown in Figure 2, the optical transmitter 20 is located at the surface (in vehicle 40, for instance) and a modulator 48 is located downhole proximate the logging tool 12. In this embodiment, the modulator 48 modulates the optical signal sent from the surface optical transmitter 20 in a way that transmits the relevant data from the logging tool 12. The modulator 48 changes a property of the optical signal, such as intensity, frequency, polarization state, and phase. In other words, the modulated signal effected by the modulator 48 becomes the optical signal with the data. Receiver 44 receives the modulated signal and converts it back into the logging tool 12 data. Modulator 48 may be a reflector functionally connected to the converter 18. Converter 18 may activate the modulator 48 depending on the electrical signals it is converting. In one embodiment, the modulator 48 also acts as the converter 18.

In addition to enabling the real-time transmission of the logging tool 12 data, use of a fiber optic line 14 also allows a distributed temperature measurement to be taken along the length of the fiber optic line 14 or the plurality of optic fibre lines disposed inside the tube. In this embodiment, an optical transmitter, such as 20, should be located at the surface. Generally, pulses of light at a fixed wavelength are transmitted from the optical transmitter 20 through the fiber optic line 14. At every measurement point in the line 14, light is back-scattered and returns to the surface equipment 44. Knowing the speed of light and the moment of arrival of the return signal enables its point of origin along the fiber line 14 to be determined. Temperature stimulates the energy levels of the silica molecules in the fiber line 14. The back-scattered light contains upshifted and downshifted wavebands (such as the Stokes Raman and Anti-Stokes

Raman portions of the back-scattered spectrum) which can be analyzed to determine the temperature at origin. In this way the temperature of each of the responding measurement points in the fiber line 14 can be calculated by the equipment 44, providing a complete temperature profile along the length of the fiber line 14. This general fiber optic distributed temperature system and technique is known in the prior art. If this technique is used, the fiber optic line 14 would be connected to a distributed temperature measurement system receiver, which can be a unit within the receiver 44 and which can be an optical time domain reflectrometry unit. The fiber optic line 14 can be used concurrently as a transmitter of data from the logging tool 12, a transmitter of downhole tool activation signals (as will be described), and as a sensor/transmitter of distributed temperature measurement. In another embodiment, fiber optic line 14 may be used to take a distributed strain measurement along the length of the fiber optic line(s) 14.

For the avoidance of doubt, in one embodiment the fiber optic line 14 may be completely housed in conduit 32 and used as a sensor/transmitter of at least one measurement without also being connected to a subcomponent 17. As discussed, the measurement may comprise distributed temperature or distributed strain, among others. In this case, a log (of the particular measurement) of many wells may be performed by successively deploying and retrieving the conduit 32 and optical fiber 14 from each well. In one embodiment, a battery powered memory tool, such as a gauge, may be attached to the conduit 32, such as at the bottom of the conduit 32, to measure and record a physical parameter, such as pressure. The measurements recorded by the tool are then downloaded and analyzed when the conduit 32 and tool are retrieved to the surface of the well.

In one embodiment, conduit 32, with fiber optic line 14 therein, may also be used to actuate downhole devices. Conduit 32 may be pressurized with a fluid, wherein the pressurized

fluid actuates downhole tools such as a packer 50 or a perforating gun 52. The activation signal may be applied pressure above a certain threshold or pressure pulses with a specific signature. The downhole tool includes a signal receptor, such as a ratchet mechanism, shear pinned firing head, or a pressure transducer, which receives the activation signal and activates the downhole tool if the correct signal is received by the receptor. For instance, packer 50 may actuate to grip and seal against the wellbore walls, or thereafter, to ungrip and unseal from the wellbore walls. Also, perforating gun 52 may actuate to shoot the shaped charges 55 and create perforations 54 in the wellbore. Other downhole tools that may be activated include flow control valves, including sleeve valves and ball valves, samplers, sensors, or pumps.

In another embodiment, the same downhole tools described in the previous paragraph may be activated by optical signals sent through the fiber optic line 14 (instead of pressure signals sent through the conduit 32). In this embodiment, the downhole tool is functionally connected to the fiber optic line 14 so that a specific optical signal frequency, signal, wavelength or intensity activates the downhole tool. A photovoltaic converter can be used to facilitate the reception of the optical signal. In another related embodiment, the downhole tool is connected to a fiber optic line 14 that is not used for logging data transmission to the surface.

In another embodiment, pressure pulses through the conduit 32 and optical signals through a fiber optic line 14 can both be sent to activate the downhole tools. In one embodiment, pressure pulses through the conduit 32 and optical signals through a fiber optic line 14 can be sent simultaneously to activate different dowhole tools. In another embodiment, data in the form of optical signals can be transmitted through the fiber optic line 14 at the same time pressure signals are transmitted through the conduit 32. In yet another embodiment, data in the form of

optical signals and activation commands in the form of optical signals can be sent simultaneously through the fiber optic line 14.

Figures 1 and 2 show the use of logging system 10 is a land well. However, logging system 10 can also be used in off shore wells on platforms or located at subsea.

In operation, an operator first connects stuffing box 36 on top of wellhead 34 and begins to deploy conduit 32 from the reel 38 and into wellbore 5. As previously stated, the stuffing box 36 seals against the outside wall of the conduit 32 enabling the deployment of the logging system 10 in a wellbore 5 that is pressurized. In general, the logging tool 12 is lowered to the appropriate depth in the well and the subcomponents 17 take their relevant readings as the tools are moved in the well. In another embodiment the tools are held stationary and data is gathered whilst the tubing, tools, and optic fibre are stationary in the well. In the embodiment in which the fiber optic line 14 is deployed after the conduit 32 is in place, the pump 46 is activated and the pumped fluid acts to drag the fiber optic line 14 down the conduit 32.

The data measured by the subcomponents 17 is converted from electrical signals to optical signals by the converter 18. The optical signals are then transmitted through the fiber optic line 14 to the receiver 44 at the surface. In the embodiment in which the optical transmitter 20 is located downhole, the transmitter sends the relevant optical signals from the downhole location through the fiber optic line 14. In the embodiment in which the optical transmitter 20 is located at the surface, the transmitter 20 sends an unmodulated signal to the logging tool 12 and the modulator 48 modulates the signal so as to etch the data onto the signal that returns to the receiver 44. In all embodiments and through the use of the fiber optic line 14, the data measured by the logging tool 12 is sent to the receiver 44 real time.

For instance, logging tool 12 may be lowered so that spinner 26 and the other subcomponents 17 are adjacent perforations 54 and formation 57 so as to obtain accurate and real time data of the parameters adjacent such perforations 54 and formation 57. In the embodiment in which the fiber optic line 14 is also used as a distributed temperature measurement system, the distributed temperature measurements may be used to approximately determine flow along the length of the wellbore 5 (across different perforations), since flow acts to change the temperature along the fiber optic line 14. Furthermore, this inferred distributed flow profile along the well can subsequently be correlated with the spinner logging tool located on the lower end of the conduit 32. Using the distributed temperature measurement to approximately determine flow indicates to an operator which areas or perforations in the wellbore 5 should be correlated with the logging tool 12, such as by taking the real flow measurement using spinner 26.

The downhole tools, such as packer 50 and perforating gun 52, may be activated at any point by way of pressure signals or hydraulicly transmitted energy through the conduit 32 or optical signals through a fiber optic line 14. Having the ability to perforate a formation and then log the relevant formation in the same trip saves time and money.

Once the logging operation is completed, the logging tool 12 is raised by reversing reel 38. It is appreciated that reel 38 and the relative size of conduit 32 enables the repeated and simple deployment and retrieval of logging tool 12. Placing reel 38 on vehicle 40 or otherwise making the reel portable enables the logging system 10 to be used in multiple wellbores.

In the embodiment including only the optical fiber as a sensor of a particular measurement (such as distributed temperature or strain), the conduit 32 is deployed in the well, the measurement is taken, and the conduit 32 is then retrieved from the well. The system may

then be taken to other wellsites. In the embodiment including a battery powered memory tool, such as a gauge, the measurements taken and recorded by the tool are downloaded from the tool once the conduit 32 and tool are retrieved to the surface.

While the invention has been disclosed with respect to a limited number of embodiments, those skilled in the art, having the benefit of this disclosure, will appreciate numerous modifications and variations therefrom. It is intended that the appended claims cover all such modifications and variations as fall within the true spirit and scope of the invention.